Coupled Monte Carlo Probability Density Function/ SPRAY/CFD Code Developed for Modeling Gas-Turbine Combustor Flows

The success of any solution methodology for studying gas-turbine combustor flows depends a great deal on how well it can model various complex, rate-controlling processes associated with turbulent transport, mixing, chemical kinetics, evaporation and spreading rates of the spray, convective and radiative heat transfer, and other phenomena. These phenomena often strongly interact with each other at disparate time and length scales. In particular, turbulence plays an important role in determining the rates of mass and heat transfer, chemical reactions, and evaporation in many practical combustion devices. Turbulence manifests its influence in a diffusion flame in several forms depending on how turbulence interacts with various flame scales. These forms range from the so-called wrinkled, or stretched, flamelets regime, to the distributed combustion regime. Conventional turbulence closure models have difficulty in treating highly nonlinear reaction rates.

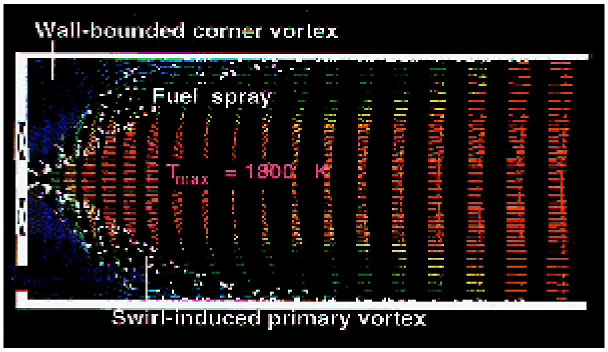
A solution procedure based on the joint composition probability density function (PDF) approach holds the promise of modeling various important combustion phenomena relevant to practical combustion devices such as extinction, blowoff limits, and emissions predictions because it can handle the nonlinear chemical reaction rates without any approximation. In this approach, mean and turbulence gas-phase velocity fields are determined from a standard turbulence model; the joint composition field of species and enthalpy are determined from the solution of a modeled PDF transport equation; and a Lagrangian-based dilute spray model is used for the liquid-phase representation with appropriate consideration of the exchanges of mass, momentum, and energy between the two phases. The PDF transport equation is solved by a Monte Carlo method, and existing state-of-the-art numerical representations (refs. 1 and 2) are used to solve the mean gas-phase velocity and turbulence fields together with the liquid-phase equations.

The joint composition PDF approach was extended in our previous work to the study of compressible reacting flows (refs. 3 and 4). The application of this method to several supersonic diffusion flames associated with scramjet combustor flow fields provided favorable comparisons with the available experimental data.

A further extension of this approach to spray flames, three-dimensional computations, and parallel computing was reported in a recent paper (ref. 5). The recently developed PDF/SPRAY/computational fluid dynamics (CFD) module combines the novelty of the joint composition PDF approach with the ability to run on parallel architectures. This algorithm was implemented on the NASA Lewis Research Center's Cray T3D, a massively parallel computer with an aggregate of 64 processor elements. The calculation procedure was applied to predict the flow properties of both open and confined swirl-stabilized spray

flames. The figure shows the global flow characteristics of a ducted-axisymmetric spray flame, showing the velocity field, temperature contours, and droplet trajectories.

Preliminary estimates indicate that it is well within today's modern parallel computer's reach to do a realistic gas-turbine combustor simulation within a reasonable turnaround time. This work was conducted in collaboration with Dr. M.S. Raju of NYMA, Inc., whose journal article with A.T. Hsu and Y.-L.P. Tsai (ref. 3) received NYMA, Inc.'s, best technical paper of the year award for 1994.



Global flow characteristics of a ducted-axisymmetric swirl-stabilized spray flame.

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